# Interim Report:

## Design Project Brief

Your consulting company has been hired by the Mars Exploration Consortium, represented by Drs. Sarkisov and Valluri. The objective of the consortium is to build a space station on Mars, capable of a continuous support of a 10 member crew.  
  
It has been planned that a re-supply mission should return to Mars every 18 months, with the main resources re-supplied being water, oxygen and food. With the current cost of the re-supplement estimated at £1 M/kg, there is a clear need for intensive onsite recycling of the resources, including water, air and waste. Your company has been hired to develop an integrated recycling solution, with an objective to minimize the weight of the re-supplement cargo.  
  
Other technologies that should be explored along with the recycling, include collection and purification of water on Mars and local production of food stock (high protein vegetables etc).  
  
The primary source of energy for the Martial station will be provided by a nuclear reactor with a 50 MWe capacity.

## Stage 1

### Initial Assumptions

* Assume no recycling.
* Human calorific, water and food requirements are the same as for earth.
* Assume gravity is constant 3.73m/s2.
* Assume conditions within space station are the same as on earth.
* Assume a thermally closed system.

### Total Crew Requirements



*Figure 1*

These requirements would have to be resupplied to the station every 18 months since we are not recycling.

## Stage 2

### Assumptions

* As for stage 1, however recycling is introduced within the space station.
* Total Crew Requirements are as previously stated.
* The resupply to the station would not be as in stage 1, however the amount needed to be resupplied has not yet been determined.
* No recycling of food (i.e. no attempt at growing biomass).

### Recycling Processes

#### Water

**Methods Used on Earth**

**Digestion** – This utilises micro-organisms to aerobically digest waste components in water and is most commonly used in municipal waste treatment.

**Bio-Reactor Systems** – Typically employs aerobic digestion by micro-organisms inside a CSTR reactor. Sequential tanks/separator recommended to reduce time to split bio-solids and treated water. This can be combined with membrane technology.

**Dark Fermentation** - Anaerobic, aerobic or facultative bacteria can be used to utilise organic wastes to produce H2, CO2, and organic acids.

**Bioremediation** - Enzymes/Bacteria/Natural organisms are used to consume contaminants.

This is similar to digestion but usually tailored to specific chemicals.

**Membrane Separations** – This can be used either biologically or chemically.

Membrane separation is designed to allow specific chemicals to permeate through. This can be pressure or electrically driven.

Pressure - Requires no chemicals, diffusion is via concentration gradients.

Electrical – electrically forces ions across the membrane leaving purified water on one side.

**Advanced Oxidation Processes** – This uses hydrogen peroxide, ozone and UV to oxidise organics and non-organics in the waste water.

**Electrocoagulation** –This uses an electric charge to cause particles in the water to coagulate which can then be removed in sludge through filtration.

**Possible Methods for Space Station**

**ISS Baseline Technology** –This uses a multistage approach to recover water, leading to the development of Orbital Replacement Units (ORUs). These are individual elements that can be replaced in orbit. Process consists of multiple filtration units, volatile removal units and a quality control unit.

**Vapour Phase Catalytic Ammonia Reactor (VPCAR)** – This is a single stage system that can handle all quality of waters to produce potable water. The main unit in VPCAR system is the wiped-film rotating disk evaporator. This removes undesirables from the feed in a bleed stream and evaporates the aqueous feed. The volatiles are then removed using an oxidation reactor which produces CO2, H2O and N2O. A reducing reactor converts N2O to O2 and N2.

**Direct Osmotic Concentration (DOC)** - This process uses direct osmosis and osmotic distillation as a pre-treatment for reverse osmosis. An osmotic agent (OA) is re-circulated on one side of a selective membrane, and waste water on the other side. Water travels down the concentration gradient and dilutes the OA. The water is then recovered from OA using reverse osmosis.

**Immobilised-cell Bioreactor (ICB)** - The ICB unit was used for organic carbon removal.

A trickling filter bioreactor (TCB) follows the ICB unit which is responsible for ammonia removal. The ICB unit consists of a cylinder with plates with equal spacing. Plates are covered with a porous polymer which supports micro-organisms. Air enters the bottom of the cylinder to induce the upwards flow of waste water. The TCB consists of a similar plate system, with micro-organism support. Reverse osmosis is utilised downstream to extract purified water.

The disadvantages associated with these methods for recycling water are shown in the table below:

|  |  |  |
| --- | --- | --- |
|  | **Processes** | **Comment** |
| **Methods used on Earth** | Digestion | Micro-organisms are highly sensitive to environmental changes such as temperature.  Relying on living organisms for life support, increases risk. |
| Bio-Reactor Systems | Extremely sensitive to temperature changes and relying on organisms for life-support increases risk. |
| Fermentation | Very sensitive to environmental changes in temperature, pH, ion concentrations etc.  It doesn’t produce potable water as it only removes approx 40% of waste components which is many organic. |
| Bioremediation | Too specific for waste water treatment, efficiency would be low. |
| Membrane Seperations |  |
| Advanced Oxidation Processes | Fast reaction rates so will be volume intensive and can be used in batch or continuous operation. However reactions must be tailored for the specific waste composition and requires input of ozone, hydrogen peroxide |
| Electro-coagulations | Produces clean palatable water and requires no added chemicals however it is energy intensive. |
| Membrane Separations | Reverse Osmosis is pressure driven and most commonly used for drinking water whereas  nanofiltration is an emerging contender.  It is highly prone to fouling which reduces its effectiveness but very energy intensive.  It creates a highly concentrated waste stream but is easily automated and removes bacteria and viruses. Membranes must be replaced every 5 years |
| **Space Methods** | ISS Baseline Technology | Relies on non-regenerative adsorption processes, therefore has a high maintenance penalty of 413 kg/year. It also has a minimal power consumption of 55 Wh/kg.  Benefits include high water purity received with a water recovery rate of 99%.  However ORUs require regular replacement of 90 days. As there is always a shuttle every 90 days the maintenance penalty for ISS can be neglected, but not the case for Mars |
| Vapour Phase Catalytic Ammonia Reactor (VPCAR) | The system is able to achieve 97% water recovery and could be increased to near 100% recovery by passing bleed stream through a lyophilizer (freeze dryer).  Requires no regular resupply to keep running.  But has a high power requirement (312 Wh/kg)  and only has a current life span of 5 years. |
| Direct Osmotic Concentration (DOC) | Is able to achieve a water recovery factor in excess of 95% and produces high quality water.  Preliminary tests indicate:  that no resupply would be required and has a  relatively low power consumption (102 Wh/kg). However these results still have to be tested for a longer duration |
| Immobilised-cell Bioreactor (ICB) | Has a high power consumption of 371 W h/kg however not self-sustaining with 119 kg/year resupply required and has the potential for 100% recovery with the use of additional units |

*Figure 2*

#### Air

**Sabatier Reaction**- This reaction comprises the reaction of hydrogen with carbon dioxide at high temperature (approx. 400˚C) and pressure in the presence of a nickel catalyst to produce methane and water. Optionally ruthenium on alumina (aluminium oxide) makes a more efficient catalyst. It is described by the following reaction:

**CO2 + 4H2 🡪 CH4 + 2H2O**

Methane is created as a by-product and can be used for fuel on the surface of mars and is currently being researched for the ISS.

**Reverse Water Gas Shift Reaction**- This reaction comprises the reaction of carbon dioxide and hydrogen (at approximately 350 ˚C) to produce carbon monoxide and water with the presence of a silica catalyst (with 5%wt Copper). It is described by the following reaction:

**CO2 + H2 🡪 CO + H2O**

The by-product (Carbon Monoxide) can be further processed into methane, methanol etc.. . Further research is required for the possible uses of this by-product.

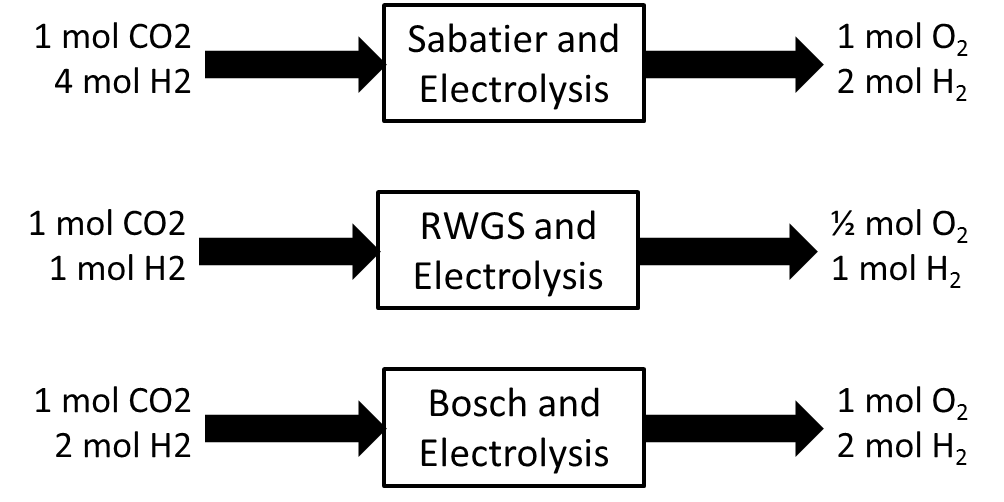
**Bosch Reaction**- This requires a higher temperature needed than for Sabatier and RWGS (approximately 530-730˚C). This could be problematic as this high temperature would need to be maintained. It has a completely closed O2 and H2 recycle and uses an Iron catalyst. The reaction is given by:

**CO2 + 2H2 → C + 2H2O**

The By-product: elemental carbon which is not useful and can foul catalyst surface therefore reduction in efficiency.

Electrolysis is employed in all the above processes to split the water into its elemental components to produce oxygen.

The quantities of moles required and produced by the aforementioned reactions are surmised in the subsequent schematic:



*Fig 2*

Other factors which may influence the decision into the best means of producing oxygen are stated in the table below:

|  |  |
| --- | --- |
| **Processes** | **Comments** |
| Sabatier Reaction | Methane produced can be used as a fuel in mars but as energy is provided another use should be explored. |
| Reverse Water Gas Shift Reaction | By-product of carbon monoxide requires further processing or there is the option of releasing it into the atmosphere but is not preferred. |
| Bosch Reaction | Very high temperatures required of up to730˚C there for may not be sustainable. |

*Figure 3*

## Stage 3

Stage 3 will consist of possible integration of resources on mars. Such as growing biomass and possible utilisation of Co2…etc.